

Introduction to an Online Coupled Ocean-Atmosphere Radiative Transfer Model

Zhonghai Jin¹, Thomas Charlock², and Ken Rutledge¹

¹AS&M, Inc., Hampton VA 23666. ²NASA Langley Research Center, Hampton 23681.

1. Description of the Model

A web site has been established recently at the NASA Langley Research Center for online simulation of solar radiation using the Coupled Ocean-Atmosphere Radiative Transfer (CO-ART) model (shown in Figure 1). This provides a tool to calculate radiances and irradiances (fluxes) at individual wavelengths or in a spectral band specified by the user at any level in the air and water. It can also calculate the water-leaving radiances at the ocean surface. Users just follow the setup menu (as shown Fig. 1) to select or specify the atmosphere (atmospheric profile, aerosol type, AOT and precipitable water, etc.) and the ocean (ocean depth, wind speed, Chl, CDOM, etc.) as well as the calculation type and output levels.

COART is established on the Coupled DIScrete Ordinate Radiative Transfer (CDISORT) or the Coupled DISORT, which was developed from DISORT, a publicly distributed software for radiative transfer by NASA. Because DISORT does not consider the refractive index variation in the medium, it is applicable only to radiative transfer problems within a medium where the refractive index variation is negligible, such as in the atmosphere with the land or ocean surface treated as bottom boundary. However, it is well known that the optical properties within the ocean affect the upwelling radiation in the atmosphere and the atmospheric properties affect the radiation penetrated into the ocean. In other words, the radiation in the atmosphere and in the ocean interact with each other and the radiative transfer process in the atmosphere and ocean should be treated consistently as one coupled system. This was done in CDISORT by including the refractive index into the radiative transfer equation. The detailed formulation and solution of the radiative transfer equations in the coupled atmosphere-ocean system by using the discrete ordinate method was given by Jin and Stamnes (1994).

However, the solution presented in Jin and Stamnes (1994) was for the flat ocean surface. In reality, the calm ocean conditions is very rare. The ocean surface roughness affects the reflection and transmission of the incident radiation at the ocean surface and, therefore, the albedo and solar heating in the ocean, as well as the sun glint pattern. We have recently included the wind blown ocean surface roughness by using the Cox and Munk (1954) surface slope distribution which is a function of wind speed (Jin et al., 2002). The sun glint induced by the surface roughness is included accordingly.

Because the radiative transfer equation, which includes the refractive index and surface roughness, is solved consistently in the coupled system, COART considers the ocean just as additional 'atmospheric layers' but with significantly different optical properties. It

The screenshot shows the Netscape browser window titled "Netscape: COART (Coupled Ocean Atmosphere Radiative Transfer Model)". The main heading is "Coupled Ocean and Atmosphere Radiative Transfer (COART)".

Select calculation type and output levels:

- ☒ Spectral fluxes (irradiance) (up and down) ($W/m^2/\mu m$) at a single wavelength: (μm)
- ☐ Spectral fluxes ($W/m^2/\mu m$) at multiple wavelengths from μm to μm at every μm .
- ☐ Integrated fluxes (W/m^2) from to μm in Spectral Resolution at μm . Filter:
- ☐ Radiances ($W/m^2/\mu m/Sr$) at wavelength: (μm).
- ☐ Radiances ($W/m^2/\mu m/Sr$) at multiple wavelengths from μm to μm at every μm .
- ? Want to include the Water-leaving radiance output? ☒ yes ☐ no
- Radiance output directions: at Zenith (deg): OR ☐ All computational zenith angles;
- Azimuth (deg): OR ☐ at every (deg) from to
- *Note: Computation time is not related to the number of output angles here. [How the angles are defined?](#)
- Output at: ☒ TOA, ☐ Surface, ☐ km above surface, and ☐ m below surface; OR ☐ All levels in atmosphere.

Solar Zenith Angle Calculations

Julian Day: GMT (hour): Latitude (deg N): Longitude (deg E):

☐ When checked, ignore Time and Location above and input your Solar Zenith Angle (deg):

Atmosphere

Select an atmospheric model:

- ☐ When checked, use reduced number of atmospheric layers to save computation time (not recommended for UV).
- ☐ When checked, input your total integrated precipitable water (g/cm^2):
- ☐ When checked, input your integrated ozone amount (atm-cm): (1 atm-cm=1000 Dobson)
- You can also change these trace gas amounts by a Factor (1.0 for no change) of \rightarrow CO₂: CH₄:
- Boundary Layer Aerosol Model: Visibility: km (at 0.55 μm)
- ☐ When checked, input your AOT at 500nm:

Ocean

Wind speed (m/s): Depth (m): Bottom albedo: Chl (mg/m^3): (Chlorophyll)

Particle scattering coefficient (m^{-1}): $b_p(\lambda) = b_p(550/\lambda)^x [Chl]^k$. Input b_0 : n : and k :

Particle scattering phase function: If use F-F func., input bb/b :

- ☐ When checked, input absorption $a(m^{-1})$: (Override the default parameterization)
- ☐ When checked, input your $a_{440}^{DOM}(m^{-1})$: (DOM absorption coefficient at 440nm)
- ☐ When checked, ignore surface roughness and assume Flat ocean surface.

... Not clear on some input? Read "The Input" section [Here](#).

For comments/questions contact Zhonghai Jin: ZJIN@larc.nasa.gov, but to read this NOTE first may help you.

Fig. 1 The web page for CO-ART.
<http://snowdog.larc.nasa.gov/jin/rtset.html>

treats the scattering and absorption in both the atmosphere and the ocean explicitly. Therefore, unlike the usual atmospheric radiative transfer models which take the ocean surface as the lower boundary with given reflectivity, COART can simulate the ocean surface reflectance.

2. Examples of Calculation by COART

The following figures present some examples of calculations. Observation data, when available, are also shown for comparison. All the radiation measurements are taken over the Chesapeake Lighthouse platform or over aircraft at NASA's CERES Ocean Validation Experiment (COVE) site, which is 25km east of the Virginia Beach in the Atlantic Ocean. The aerosol optical properties, precipitable water (PW), wind speed, Chl and the absorption properties for soluble and particulate materials in the ocean, which are used for model input, are also from in-situ measurements at COVE.

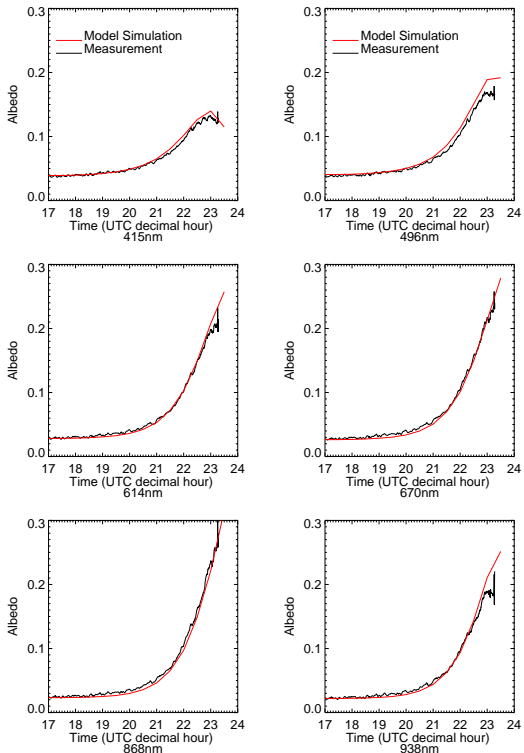


Fig. 2. Modeled (red) and measured (black) ocean albedo in the six MFRSR channels at COVE on July 31, 2001.

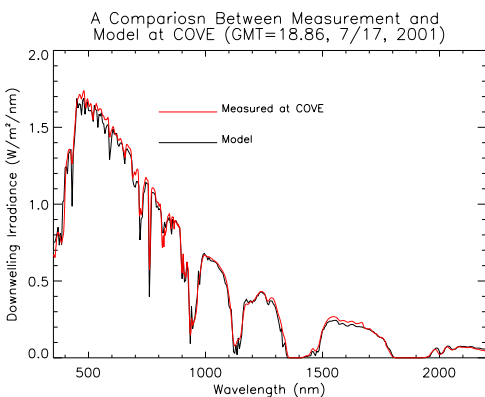


Fig. 3. An example of modeled and measured downwelling spectral irradiances.

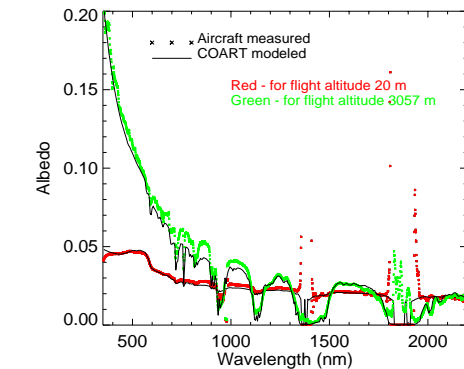


Fig. 4. A comparison of the modeled and aircraft measured albedo over the ocean in the vicinity of COVE on August 12, 2002.

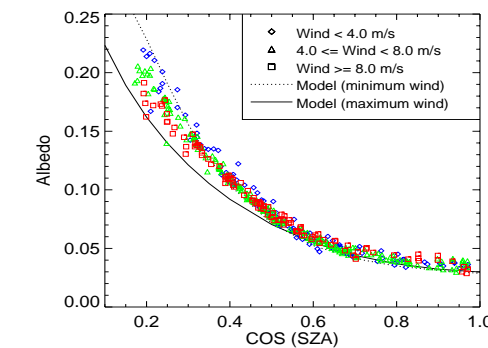


Fig. 5. Modeled and measured broadband ocean surface albedo at COVE under clear skies for a whole year.

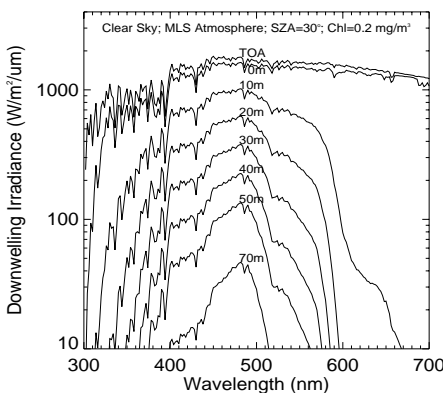


Fig. 7. Modeled downwelling irradiances at the TOA, surface and various depths in the ocean under clear sky conditions

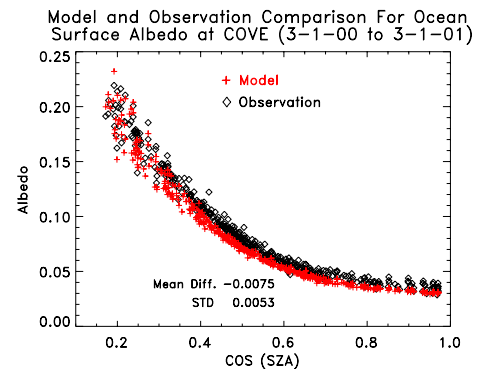


Fig. 6. Wind effects on ocean surface albedo. The observed albedo as a function of the cosine of SZA are plotted in three wind categories. The dashed line and the solid line are the modeled albedo with the minimum wind (0.48 m/s) and maximum wind (14.0 m/s) of the observations, respectively. The mean AOD and PW of measurements were used in model calculations.

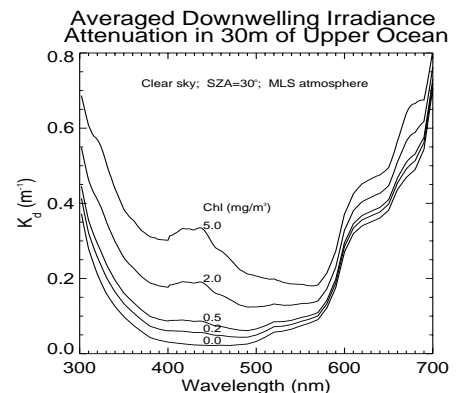


Fig. 8. Modeled downwelling flux attenuation coefficients averaged in the 30 m of upper ocean for different chlorophyll concentrations.

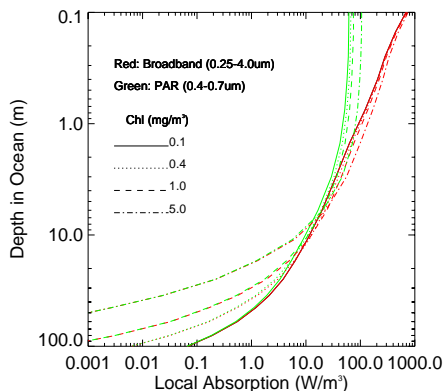


Fig. 9. Modeled local solar absorption as a function of depth. Note that the absorptions for the broadband and the PAR are overlapped at depth of about 10 m, indicating that most of radiation outside of PAR is absorbed in the few meters of the top layer. Clear sky; SZA=30°; MLS atmosphere.

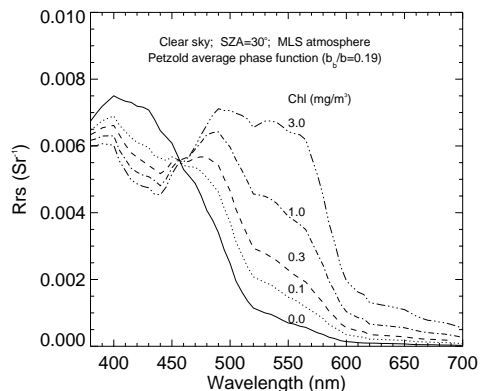


Fig. 10. Modeled remote sensing reflectance ($R_{rs} = L_w / E_d$) for different Chls. Note that the optical properties for ocean particles are based on the parameterization of Gordon and Morel (1983), which are chlorophyll related only. The actual absorption and scattering may be very different, which could result in very different L_w and R_{rs} , especially in the blue.

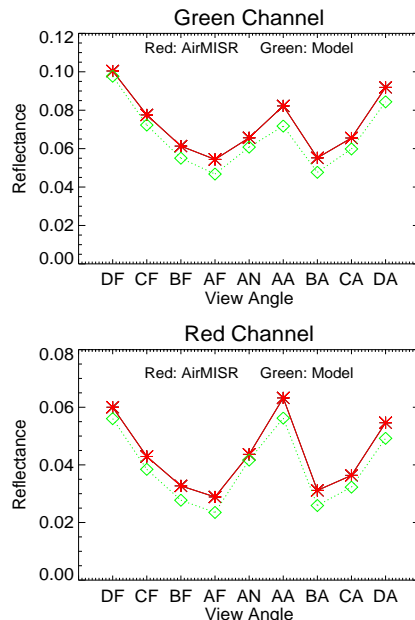


Fig. 11. The equivalent reflectance measured from nine view angles by AirMISR at 20 km above the ocean at COVE

and comparison with model simulation. Note that the view directions 'AA' and 'AN' are right in the sun glint region.

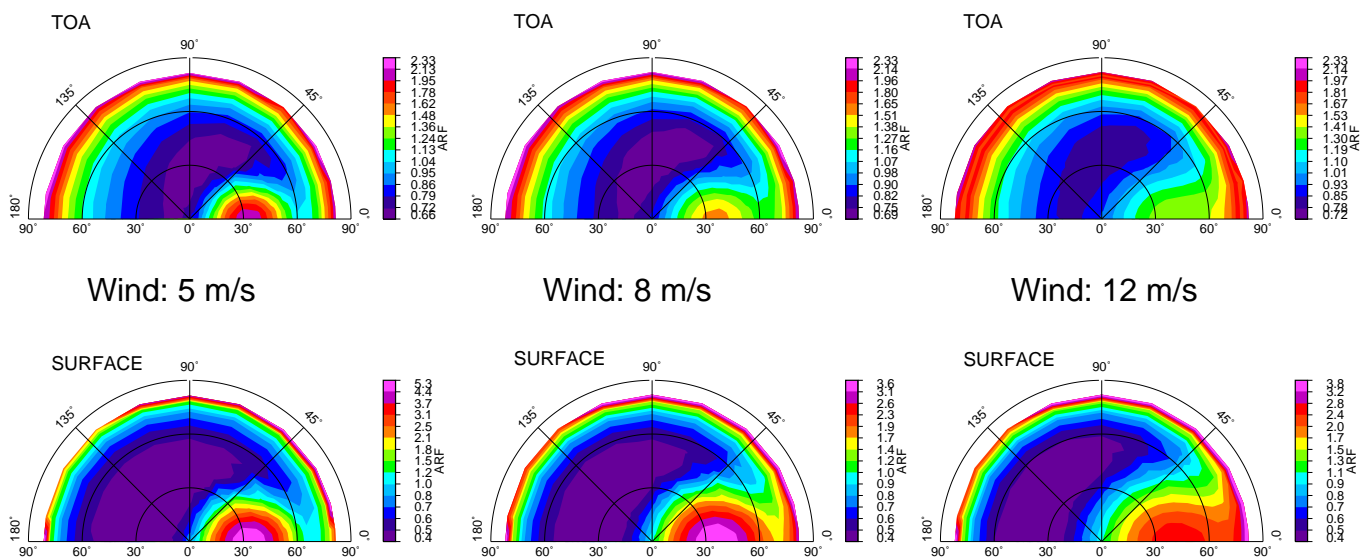


Fig. 12. Modeled BRDF at the TOA and the ocean surface for three different wind speeds. Clear sky; SZA=30°; MLS atmosphere; no aerosol. Note the sun glint variations with wind speed.

3. Features to be Added

COART is still under development. The online model does not have the full capability as the offline model yet. Some new features will be added to the online input/output menu. These include but not limited to the following:

- Input vertical profile of water vapor and aerosol.
- Input aerosol optical properties at multiple wavelengths.
- Input Chl profile in ocean.
- Input clouds.
- Implement the band model for fast computation over broadband.

If you want to receive the upgrade information, go to <http://snowdog.larc.nasa.gov/jin/rtnote.html>, and add your email to the mailing list.

4. References

- Cox, C., and W. Munk, 1954: Measurement of the roughness of the sea surface from photographs of the sun's glitter, *J. Opt. Soc. Am.*, 44, 838-850.
- Jin, Z., and K. Stamnes, 1994: Radiative transfer in nonuniformly refracting layered media: Atmosphere-ocean system. *Appl. Opt.*, 33, 431-442.
- Jin, Z., T.P. Charlock, K. Rutledge, 2002: Analysis of broadband solar radiation and albedo over the ocean surface at COVE. *J. Atmos. Oceanic Technol.*, 19, 1585-1601.

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